

3. Research Component Summaries

a. Remote Sensing of Greenbug and Russian Wheat Aphid Infestations

i. Characterization Of Aphid-Induced Stress In Wheat Under Field Conditions Using Remote Sensing

Written by Mustafa Mirik

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During the late fall of 2003 and spring of 2004, the feasibility of a commercially-available hyperspectral hand-held remote sensing instrument to predict aphid density and damage was studied. The following paper summarizes the major findings of the research and it was published in 2004 Bushland Agricultural Day (Summer Crop Field Day) Proceedings (p. 88-98).

Abstract: This work was carried out to investigate the relationship between remotely sensed data and aphid density in field conditions. A hyperspectral ground spectrometer was used to collect percent reflectance data over 0.25 m² aphid stressed and non-stressed wheat (*Triticum aestivum* L.) plots in the fields located in Texas, Oklahoma, and Colorado. Bird cherry-oat aphid (*Rhopalosiphum padi* Linnaeus), greenbug (*Schizaphis graminum* Rondani), and Russian wheat aphid (*Diuraphis noxia*) were counted in each of the 0.25 m² aphid stressed wheat plots. Paired t-test indicated that percent reflectance values in the 400-900 nm region of the spectrum from aphid stressed and non-stressed wheat were statistically significant. In addition to the statistical comparison of percent reflectance, a total of 25 spectral vegetation indices were calculated from the reflectance data and regressed against the number of aphids. A wide array of relationships was found between spectral reflectance and aphid density. For example, the R² values were 0.85 for greenbug plus bird cherry-oat aphid and 0.97 for Russian wheat aphid. These preliminary results strongly indicated that remote sensing techniques, both hyperspectral and multispectral imageries, are highly promising to predict aphid density and discriminate aphid-induced stress from un-infested wheat in field conditions.

INTRODUCTION

Both hyperspectral and multispectral remote sensing technologies have undergone rapid development for a wide setting of applications including precision agriculture because they assist researchers in generating a variety of information at regional and global levels. In addition, various authors (Gemmell and Varjo, 1999; Bork et al., 1999) have argued that remote sensing has advantages over the traditional ground-based monitoring methods, because the latter is

laborious, slow, limited to the localized areas, subject to the great variation, and constrained by the lack of access. In addition, the same remotely sensed data can be used for multiple purposes by the same or different investigators.

In recent years, the use of remote sensing has dramatically increased the ability of scientists, managers, and decision-makers to study spatial data in terms of collecting, storing, manipulating, processing, visualizing, integrating, quantifying, monitoring, and managing the available information for present and future needs. Much effort has been assigned to estimate crop characteristics, such as green canopy health and cover, and to discriminate them in a spatially complete manner using visible and infrared spectral data. The goal of the present study was to evaluate the remotely sensed data to detect aphid infestation and estimate aphid density in wheat fields.

METHODOLOGY

We collected aphid density; greenbug and Russian wheat aphids; and spectral reflectance data in and over stressed and non-stressed 0.25 m^2 wheat plots in TX, OK, and CO. Reflectance data and digital images were gathered by a hyperspectral ground spectrometer and a digital camera over aphid infested wheat and un-infested wheat nearby. Sometimes, at least 30 tillers were cut at ground level and transported to laboratory to count the number of aphids per 0.25 m^2 sample plot. The remaining tillers in each plot were tallied in the fields to estimate aphid density for each sample plot (Figure 1). The other times, aphid density was determined in the fields by counting all aphids within plots during the early growing season (Figure 1) or clipping all plants and counting aphid in the laboratory during the late growing season (Figure 1). All in all, aphid density was determined at 0.25 m^2 level for each sample. This methodology was applied to all sites for determining actual aphid density in this study.



Figure 1: Clipping wheat in a 0.25 m^2 plot to be transported to laboratory so as to count aphid (left), counting aphid on wheat plants in laboratory (middle) and in the fields (right).

RESULTS AND DISCUSSION

Reflectance patterns gathered by Ocean Optics ground hyperspectral spectrometer for greenbug stressed alone, combination of greenbug and abiotic-stressed and non-stressed wheat near Dumas, Texas were plotted across the visible and near infrared (NIR) range of the spectrum

(400-900 nm) and displayed in Figure 2. As it seen in Figure 2, Non-stressed wheat reflected less light than aphid stressed alone and combination of abiotic and aphid stressed wheat in the visible part of the spectrum but this trend switched in the NIR spectral window. The similar results were observed by plotting the visible and NIR reflectance data collected near Amarillo, Texas for Russian wheat aphid and abiotic stress and non-stress in wheat as well as exposed soil. Figure 2 depicts what was expected that healthy wheat absorbed more visible light for photosynthesis, while injured plants caused by aphid were not able to capture as high light as healthy wheat did for biomass accumulation. This result is in agreement with the findings of Riedell and Blacmer (1999) who reported the spectral properties of Russian wheat aphid and greenbug feeding effects in wheat at the leaf level.

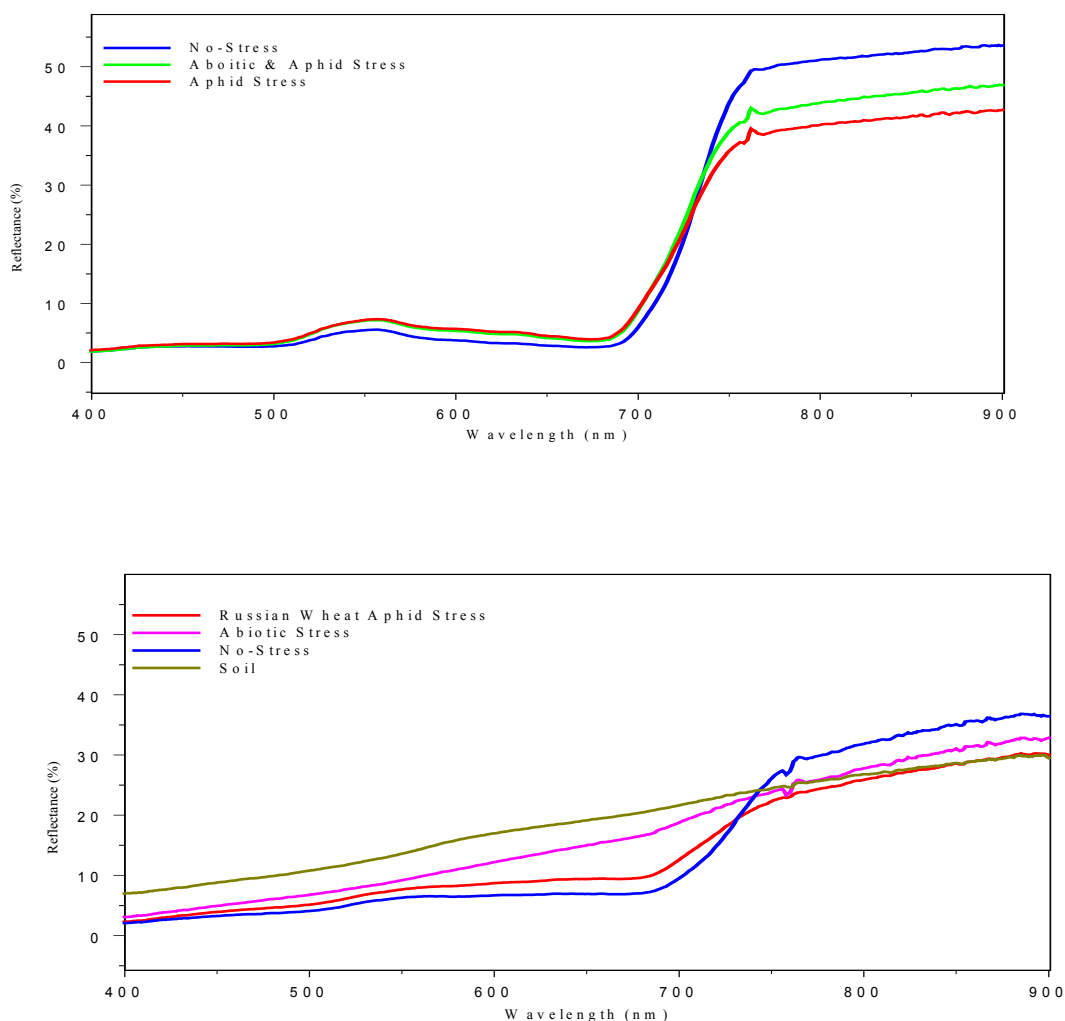
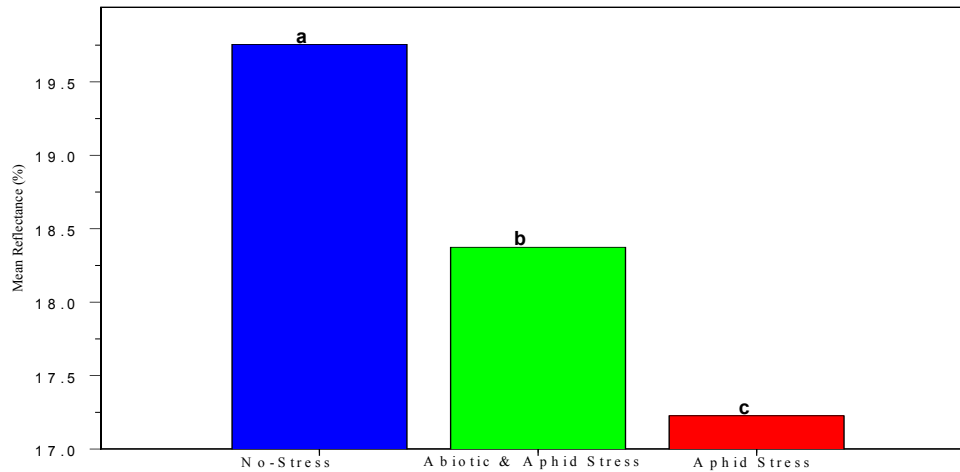


Figure 2: Spectral properties of greenbug-stressed alone, combination of abiotic and greenbug-stressed, and non-stressed wheat (top), Russian wheat aphid-stressed, water-stressed, healthy wheat, and exposed soil (bottom) across the visible and NIR spectrum.

Mean comparison of reflectance data collected for healthy, combination of greenbug and abiotic stress, and aphid stress alone in wheat crop was made and statistically significant difference was found among the entities in question across the visible and NIR spectrum (Figure 3). The same comparison was also made for the Russian wheat aphid stressed and healthy wheat and it resulted with the similar outcomes to greenbug (Figure 3). Both Figures, 2 & 3, strongly suggest that use of hyperspectral or multivariate imagery to delineate aphid-induced stress in wheat because most of the image analyses are based on the statistical similarities and/or dissimilarities between or among the surface properties found in an imagery. For our case, surface properties are aphid stressed; or other types of stress; and non-stressed wheat in the fields.



| Wavelength (nm) | Russian Wheat Aphid Stress | No Stress |
|-----------------|----------------------------|-----------|
| 400 - 500 | a | b |
| 500 - 600 | a | b |
| 600 - 700 | a | b |
| 700 - 800 | a | b |
| 800 - 900 | a | b |
| 400 - 900 | a | a |

Figure 3: Statistical comparison of three levels of stress measured by reflectance data: greenbug, combination of greenbug and abiotic (top), Russian wheat aphid stressed and non-stressed in wheat (bottom) in the visible and NIR range of the spectrum. Note: Different letters in adjacent columns indicate statistical significance at $\alpha = 0.05$

One of the digital images of greenbug infested wheat plots is shown in Figure 4. Digital images of greenbug-induced stress in wheat were analyzed using ASSESS (Image Analysis Software

for Plant Disease Quantification) and percent greenbug damage was estimated as shown in Figure 4. A strong correlation ($R^2 = 0.85$) was found by regressing the percent damage against greenbug density (Figure 4). The negative slope of the regression line or increased percent greenbug damage while decreasing greenbug density in Figure 4 makes sense because most likely greenbug moved to new spots from injured plants or died due to reduction in food resources. This also appears to be a function of sampling date.

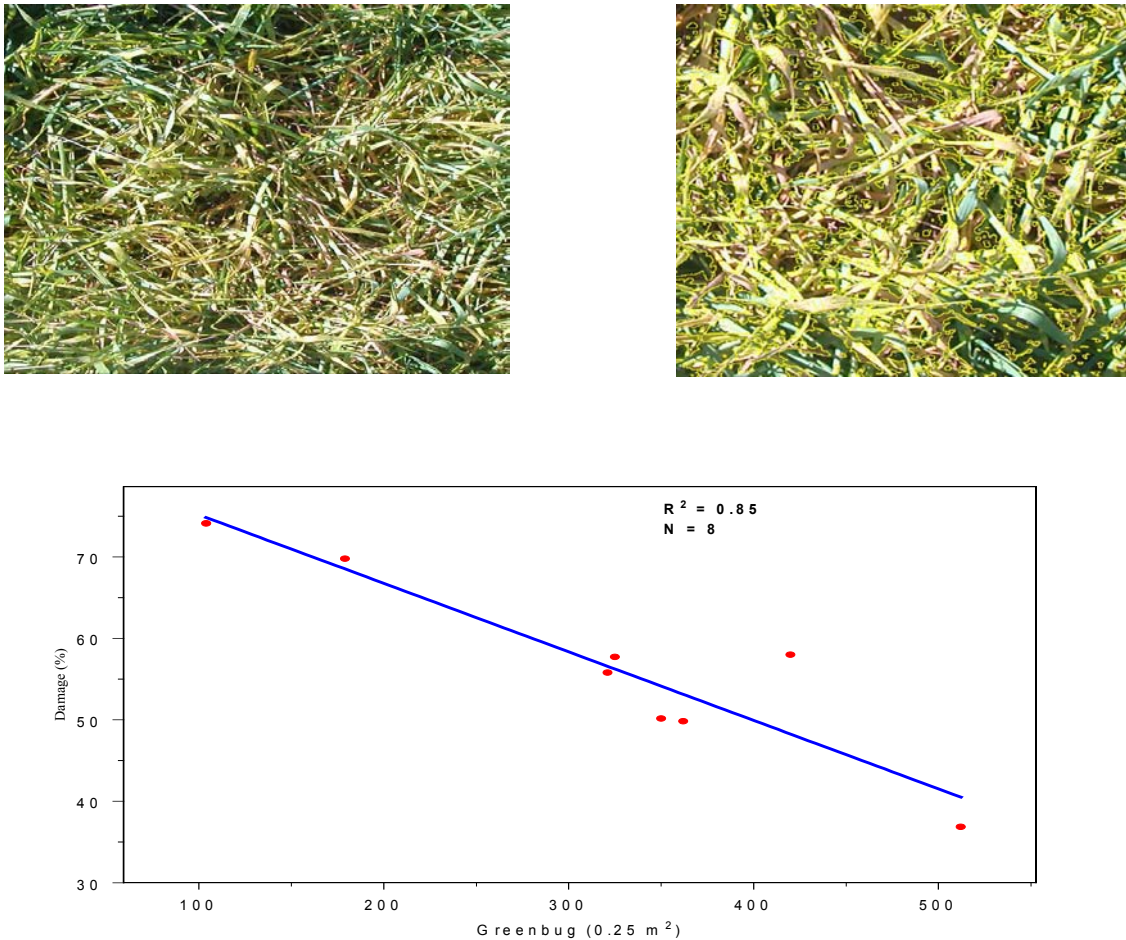


Figure 4: Greenbug-induced stress (upper left), estimation of damage caused by greenbug feeding (upper right), and the relationship between greenbug density and percentage damage (bottom) in wheat.

In order to investigate the relationship between aphid density and spectral data, 25 vegetation indices were calculated from reflectance data and regressed against aphid density. Very good to strong correlations explained by the R^2 values were found. The relationships explained by the R^2 values, spectral vegetation indices used to predict aphid density, and wavelength centers used to calculate spectral vegetation indices are given in Figure 5.

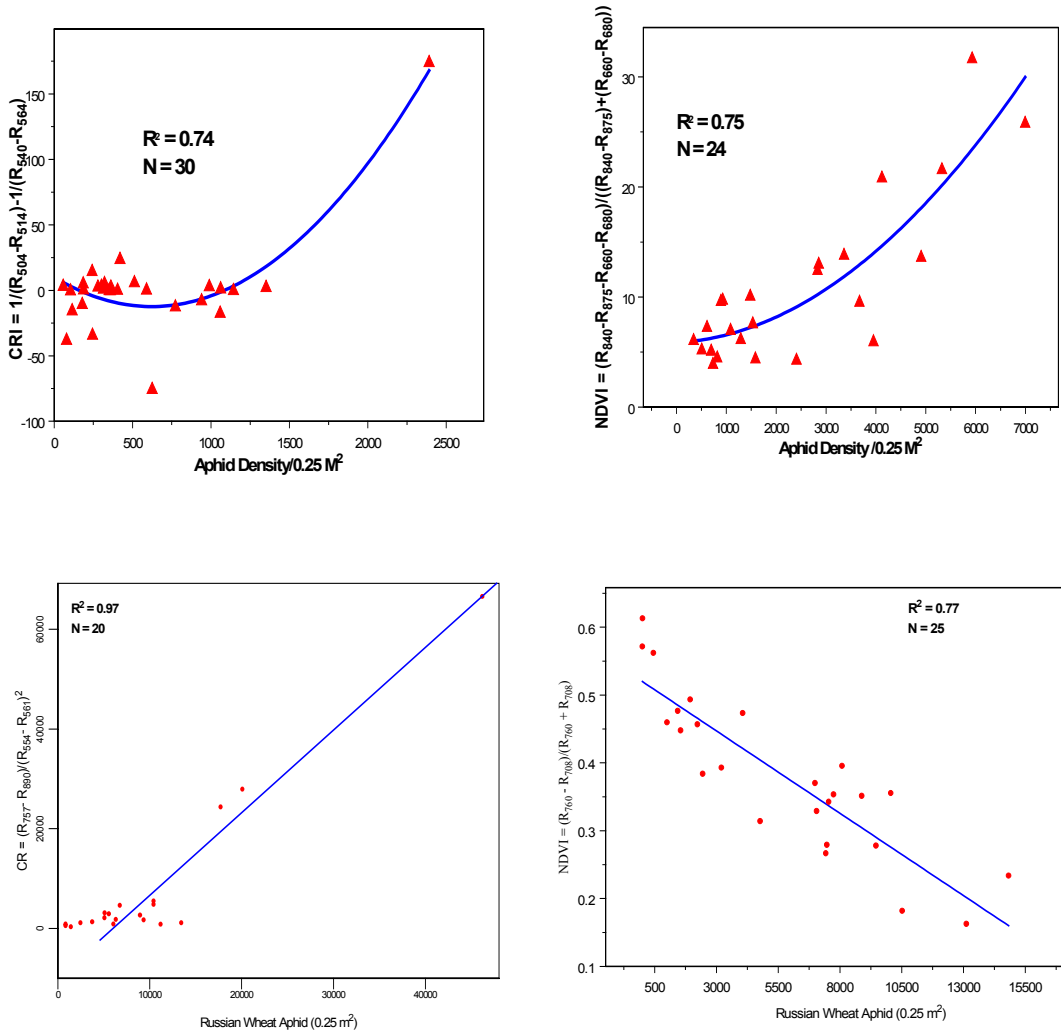


Figure 5: Plots of non-linear regression for aphid density (greenbug + bird cherry-oat aphid) and spectral vegetation indices (first two) and linear regression for Russian wheat aphid (last two). Data in the first plot were collected in a volunteer wheat field near Dumas TX, in the second plot data were gathered in a planted winter wheat field near Oklahoma City, OK, in the third plot data were obtained in a wheat field near Amarillo, TX, and in the last plot data were collected in a wheat field near Lamar, CO.

In addition to aphid and remote sensing data analysis, this work also dealt with prediction and comparison of wet and dry biomass from Russian wheat aphid infested and non-infested wheat near Amarillo, TX. It can be seen in Figure 6 that wet and dry biomass from Russian wheat aphid-stressed wheat were significantly different from non-stressed wheat. This result was also observed by Riedell and Blackmer (1999) who found reduction in dry weight of wheat leaves caused by Russian wheat aphid feeding when compare to Russian wheat aphid free leaves.

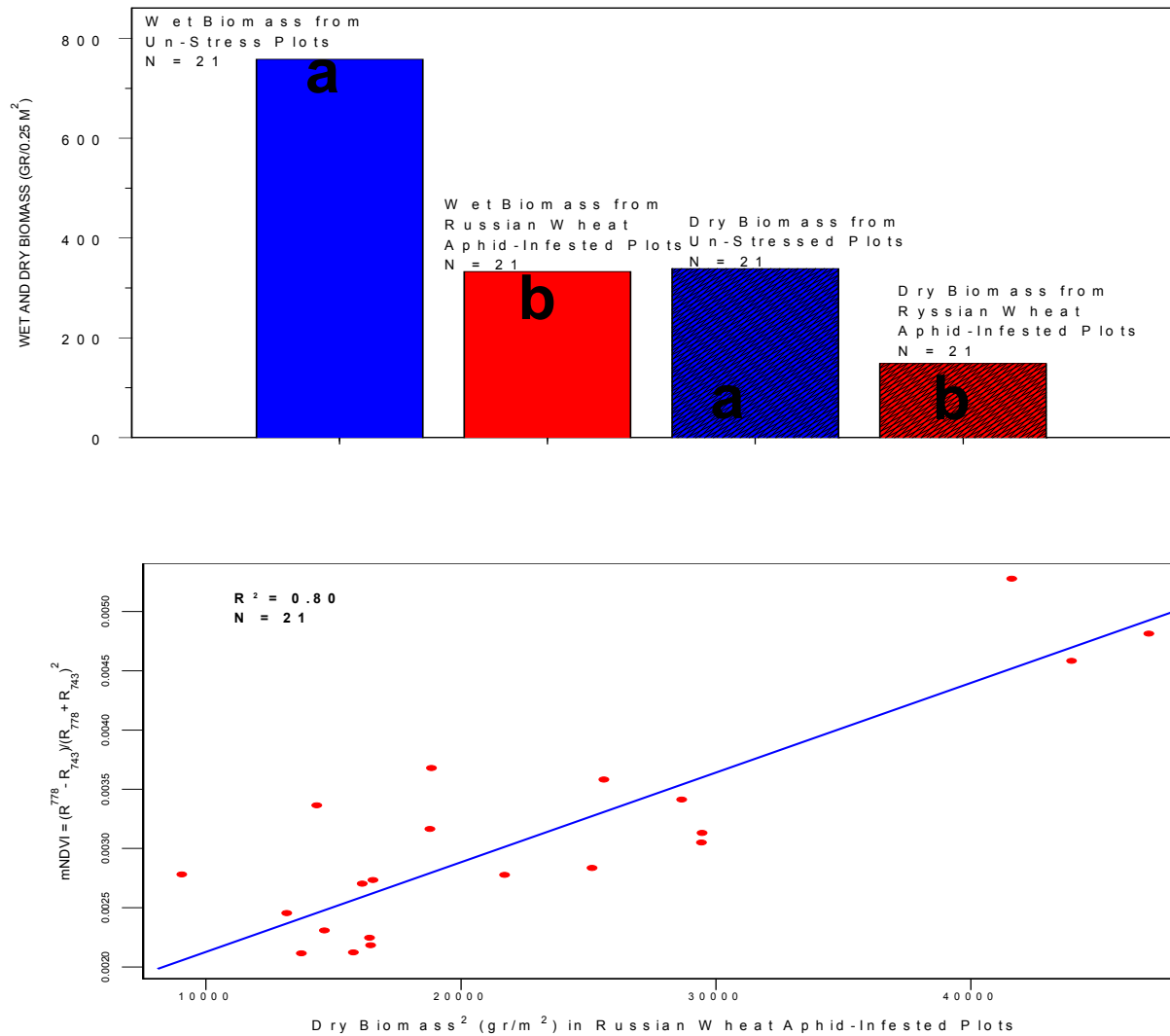


Figure 6: Dry and wet biomass from Russian wheat aphid-infested and un-infested plots (top) and the relationship between biomass gathered from Russian wheat aphid-infested plots and modified Normalized Difference Vegetation Index (mNDVI) (bottom).

CONCLUSIONS AND DIRECTIONS FOR FUTURE WORK

This work has shown that remote measurement of aphid-induced stress to estimate aphid density and separate the injured wheat from the healthy one at 0.25 m² canopy level in the field conditions was successfully employed.

Results reported in this work indicate feasibility of using remote sensing imageries at large scales to detect and discriminate aphid feeding damage in wheat and possibly in other crops.

We expect to work spectral measurements of interactions between aphid pest and host plants at larger scales using hyperspectral and multirate imageries.

Future work will continue to collect spectral data for aphid infestation on agricultural crops not only in the field conditions but also controlled environment.

Discrimination of three level of stress: water, nutrient, and aphid in wheat and sorghum will be the focus of the work in the near future.

Future work will also concentrate to develop and validate a spectral aphid stress index for major crops.

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- Peñuelas, J., R. Isla, I. Filella, and J. L. Araus. 1997. Visible and near-infrared reflectance assessment of salinity effects on Barley. *Crop Sci.* 37:198-202.
- Reidell, W. E. and T. M. Blackmer. Leaf reflectance spectra of cereal aphid-damaged wheat. *Crop Sci.* 39:1834-1840.

ii. The search for a Distinct Spectral Signature for Greenbug and Russian Wheat Aphid Injured Wheat

Written by Zhiming Yang

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Detection of Greenbug Infestation Using Ground-based Radiometry

Zhiming Yang

Challenges to detection

- Coexistence of water stress and greenbug infestation
- Confusion with infestation by Russian Wheat Aphid
- Timing issues in detection
 - Before greenbug density reaches maximum
 - Thresholds may be different at different growth stages

Principles of Stress Detection By Remote Sensing

- Leaf(canopy)reflectance
 - determined by leaf surface properties, internal structure, the concentration and distribution of biochemical components
 - most important: water and chlorophyll
- Canopy temperature – leaf transpiration

Research objectives

- To identify bands sensitive to greenbug infestation
- To identify vegetation indices sensitive to greenbug infestation
- Differentiating greenbug infestation with water stress and infestation by RWA
- To study impact of plant growth stage

Experiment facilities



Greenhouse and cropscan radiometer system



Sensors



Data logger



CR-10 Weather station

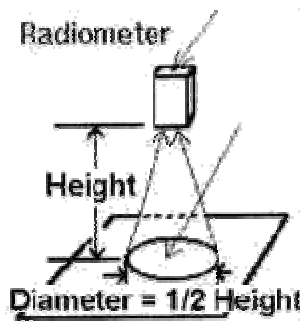


HOBO sensor

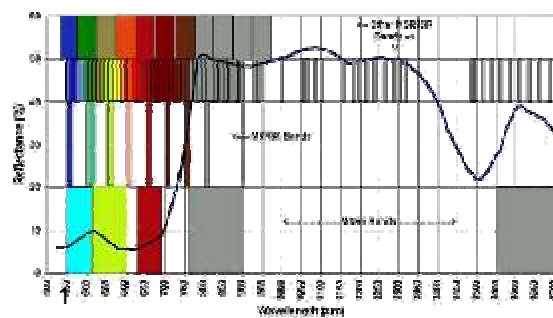


Soil moisture sensor

Operation and bands of Cropscan radiometers (MSR16R)



Field of view = 28°



Available bands for MSR16R

Band distribution for the Cropscan radiometer (MSR16R) in this study

| Band name | | Narrow ($\pm 5\text{nm}$) | Broad ($>\pm 30\text{nm}$) |
|-----------------------|-------|-----------------------------|------------------------------|
| Visible | Blue | 1. 450 | 485 |
| | Green | 2. 580 | 560 |
| | Red | 620 | 660 |
| | | 630 | |
| | | 670 | |
| | | 680 | |
| | | 694 | |
| NIR (Near Infrared) | | 800 | |
| | | 900 | 830 |
| | | 950 | |
| MIR (Middle Infrared) | | 1480 | 1650 |

Experiment methods

- Planting:
 - Variety - TAM 107
 - Seed spacing 1in. x 3 in.
 - Plastic flats - 24 in. x 16 in. x 8.75 in (4)
 - Soil - Redi-earth
 - Plug and Seedling Mix (5)
 - Pesticides – Marathon(1% granular)
- Infesting:
 - At two leaf stage, 15 days after sowing
 - Greenbug (biotype E), wingless adults (3)
 Density: 1 greenbug per plant

Experiment methods cont.

- Data collection
 - Reflectance measurements at nadir angle at noon time daily
 - Temperature and humidity using CR -10 or Hobo temperature and humidity sensor
 - Greenbug density (count GB on 10 plants and get average every three days)
- Plant Management
 - Fertilized once two weeks;
 - Watered 1-2 times a week.

Experiments conducted in this study

| Treatments | Experiment Name | Sym-bol | Purpose | Time Periods |
|---|------------------------------|---------|------------------------------------|-----------------------|
| greenbug-infested without pesticide | Sensitivity experiment 1 | SEex 1 | Test sensitivities of band | Jan16 - Mar 12, 2002 |
| non-infested with pesticide | Sensitivity experiment 2 | SEex 2 | and vegetation indices | Mar16 – May 1, 2002 |
| control (non-infested without pesticide) | Sensitivity experiment 3 | SEex 3 | | Nov 11 – Dec 24, 2003 |
| greenbug-infested without water stress (NW+I) | Differentiating experiment 1 | Dllex 1 | Differentiate greenbug infestation | Nov 5 – Dec 8, 2002 |
| non-infested with water stress (W+NI) | Differentiating experiment 2 | Dllex 2 | and water stress | Mar17 – Apr 13, 2003 |
| control (non-infested without water stress) (NW+NI) | Differentiating experiment 3 | Dllex 3 | | Nov 11 – Dec 24, 2003 |
| infested and water stress (W+I). | | | | |

Experiments conducted in this study (continued)

| Treatments | Experiment Name | Sym-bol | Purpose | Time Periods |
|---|-----------------------|---------|-----------------------------------|-----------------------|
| greenbug-infested at two-leaf stage | Stage experiment | STex | Test impact of growth stage | Jan 18 – Feb 26, 2003 |
| greenbug-infested at tillering stage | | | | |
| control (non-infested) at two-leaf stage | | | | |
| control (non-infested) at tillering stage | | | | |
| greenbug-infested | GB and RWA experiment | GRex | Compare two kinds of infestations | Oct 30 – Nov 20, 2003 |
| Russian Wheat Aphid - infested | | | | |
| control (non-infested) | | | | |

Data Processing and Analysis

- SAS program for repeated measures –
PROC MIXED, PROC GLM
- Threshold Day and Maximum Day
Threshold Day
- the day subsequent to which there is always a significant difference between treatments;
Maximum Day -
the day at which greenbug density reaches maximum
- Correlation analysis –
Correlation coefficients: differences in reflectance/vegetation indices vs. GB density
– Significance test for correlation ($p=0.05$)

Data Processing and Analysis

- Sensitivity analysis (band and indices)

$\text{Sensitivity}_{\text{band}} = (\text{Ref}_{\text{inf}} - \text{Ref}_{\text{ctrl}}) * 100 / \text{Ref}_{\text{ctrl}}$, where

$\text{Sensitivity}_{\text{band}}$ – Sensitivity for a given band

Ref_{inf} – Canopy reflectance of infested plants;

Ref_{ctrl} – Canopy reflectance of control plants.

- Differentiating water stress and greenbug infestation: -
Compare Threshold Day and Maximum Day
- Impact of growth stage on sensitivity of band or VI -
Testing correlation and relative sensitivities
- Compare two kinds of infestations
- Compare Threshold Day and Maximum Day

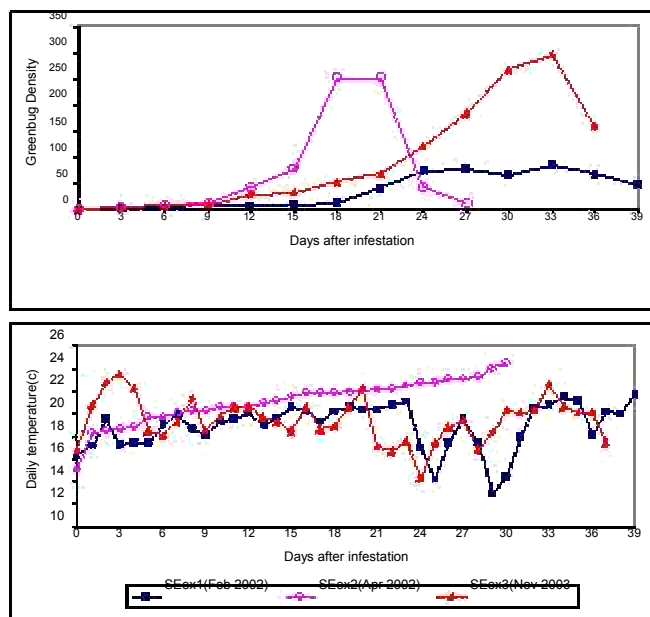
Vegetation indices used in various studies

| Vegetation Index | Formula |
|---|---|
| Atmospheric Resistant Vegetation Index, ARVI (Kaufman and Tanre, 1996) | $\text{ARVI} = (\text{NIR} - (2\text{red} - \text{blue})) / (\text{NIR} + (2\text{red} - \text{blue}))$ |
| Difference Vegetation Index, DVI (Tucker, 1979) | $\text{DVI} = \text{NIR} - \text{Red}$ |
| Enhanced Vegetation Index, EVI (Verstraete and Pinty, 1996) | $\text{EVI} = (1+L) (\text{NIR} - \text{red}) / (\text{NIR} + \text{C1} * \text{red} - \text{C2} * \text{blue} + L)$ C1=6.0, C2=7.5, L=1.0 |
| Global Environmental Monitoring Index, GEMI (Pinty and Verstraete, 1992) | $\text{GEMI} = (1 - 0.25 * (\text{red} - 0.125)) / (1 - \text{red})$ $ \text{red} = [2(\text{NIR}^2 - \text{red}^2) + 1.5\text{NIR} - 0.5\text{red}] / (\text{NIR} + \text{red} + 0.5)$ |
| Modified Soil Adjusted Vegetation Index Two, MSAVI2 (Qi et al., 1994) | $\text{MSAVI2} = 1/2 * [(2 * (\text{NIR} + 1)) - (((2 * \text{NIR}) + 1)^2 - 8 (\text{NIR} - \text{red}))^{1/2}]$ |
| Optimized Soil Adjusted Vegetation Index, OSAVI (Rondeaux et al., 1996) | $\text{OSAVI} = ((\text{NIR} - \text{red}) / (\text{NIR} + \text{red} + L)) * (1 + L)$ L=0.16 |
| Normalized Difference Vegetation Index, NDVI (Rouse et al., 1973) | $\text{NDVI} = (\text{band1} - \text{band2}) / (\text{band1} + \text{band2})$ |

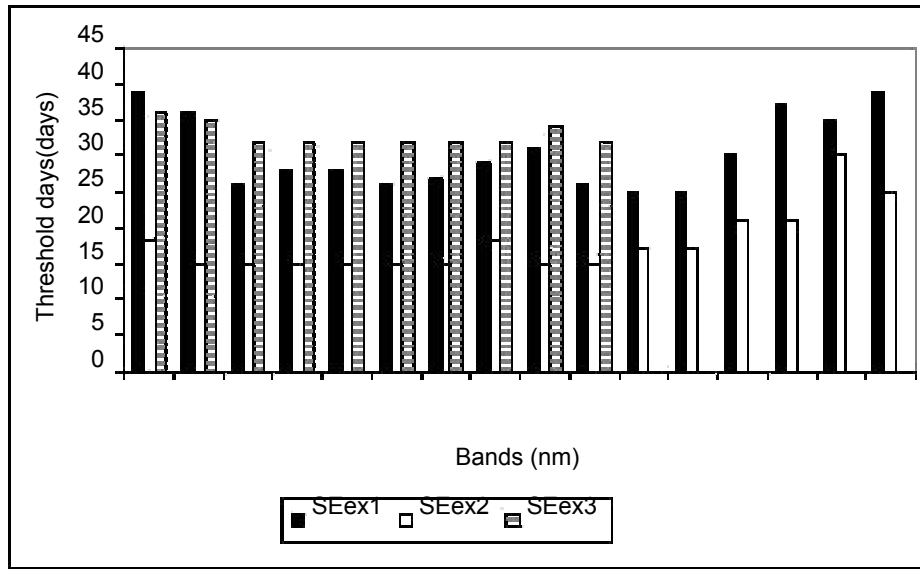
Vegetation indices used in various studies (continued)

| Vegetation Index | Formula |
|--|---|
| Normalized total Pigment to Chlorophyll Index, NPCI (Riedell and Blackmer, 1999) | $NPCI = (R680 - R430) / (R680 + R430)$ |
| Ratio Vegetation Index, RVI (Jordan, 1969) | $RVI = \text{band1} / \text{band2}$ |
| Soil-Adjusted Vegetation Index, SAVI (Huete, 1988) | $SAVI = (1 + L) * (\text{band1} - \text{band2}) / (\text{band1} + \text{band2} + L); L = 0.5$ |
| Structural Independent Pigment Index, SIPI (Penuelas and Inoue, 1999) | $SIPI = (R800 - R450) / (R800 - R680)$ |
| Specific Leaf Area Vegetation Index, SLAVI (Lymburner et al., 2000) | $SLAVI = NIR / (\text{Red} + MIR)$ |
| Vegetation Index One, VI1 (Viña, 2002) | $VI1 = NIR / \text{green} - 1$ |
| Vegetation Index Two, VI2 (Viña, 2002) | $VI2 = R800 / R694 - 1$ |
| Yellowness Index, YI (Adams et al., 1999) | $YI = (R580 - 2R630 + R680) / \lambda^2, \lambda = 50 \text{ nm}$ |
| Water Band Index, WBI (Riedell and Blackmer, 1999) | $WBI = R950 / R900$ |

Temporal changes in greenbug densities and daily temperatures



Threshold Days for bands



Maximum Days: 33(SEex1), 21(SEex2), 33(SEex3)

Correlation Coefficients and sensitivities of bands

| <u>Band (nm)</u> | <u>Correlation coefficient</u> | | | <u>Difference (%)#</u> | | | |
|----------------------|--------------------------------|----------------|----------------|--------------------------|--------------|--------------|--------------|
| | SEex1 | SEex2 | SEex3 | SEex1 | SEex2 | SEex3 | Average |
| BAND560 | 0.7924* | 0.9647* | 0.9211* | 20.29 | 36.49 | 31.68 | 29.49 |
| BAND580 | 0.7104* | 0.9632* | 0.9310* | 20.12 | 46.35 | 39.8 | 35.42 |
| BAND620 | 0.6785* | 0.9122* | 0.8800* | 21.76 | 67.42 | 28.76 | 39.31 |
| BAND630 | 0.7318* | 0.9459* | 0.8877* | 23.88 | 66.43 | 34.3 | 41.54 |
| BAND660 | 0.7701* | 0.9039* | 0.8741* | 20.56 | 62.59 | 28.71 | 37.29 |
| BAND670 | 0.6924* | 0.9592* | 0.9066* | 17.65 | 55.09 | 32.29 | 35.01 |
| BAND680 | 0.7804* | 0.9480* | 0.8373* | 20.42 | 66.92 | 17.34 | 34.89 |
| BAND694 | 0.8288* | 0.9093* | 0.8992* | 22.85 | 73.79 | 30.31 | 42.32 |
| BAND800 | -0.7271* | -0.9255* | 0.1552? | -6.32 | -19.59 | -12.47 | -12.79 |
| BAND830 | -0.7099* | -0.9313* | 0.2272? | -5.27 | -17.07 | -9.49 | -10.61 |

*: significant at 0.05 level; ?: not significant

#: Difference in reflectance between infested and control plants at Maximum Day

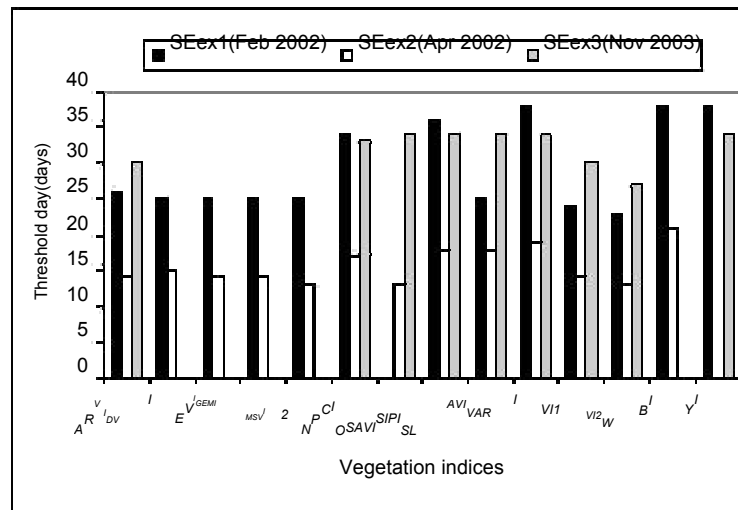
Most sensitive

Correlation Coefficients and sensitivities of selected VI

| vegetation indices | correlation coefficients* | | |
|--------------------|---------------------------|---------|---------|
| | SEex1 | SEex2 | SEex3 |
| NDVI_830_560 | -0.7208 | -0.9471 | -0.8929 |
| RV1_800_620 | -0.7761 | -0.96 | -0.9511 |
| RV1_800_630 | -0.8089 | -0.977 | -0.9421 |
| RV1_800_670 | -0.7849 | -0.9615 | -0.9413 |
| RV1_800_680 | -0.8371 | -0.9652 | -0.9176 |
| RV1_800_694 | -0.8536 | -0.9404 | -0.9547 |
| RV1_830_485 | -0.7524 | -0.9698 | -0.8961 |
| RV1_830_660 | -0.8492 | -0.9326 | -0.9458 |
| RV1_900_450 | -0.8033 | -0.9382 | -0.7377 |
| RV1_900_580 | -0.7937 | -0.9524 | -0.8129 |
| RV1_900_620 | -0.7682 | -0.9626 | -0.8655 |
| RV1_900_630 | -0.8092 | -0.9808 | -0.8496 |
| RV1_900_680 | -0.8421 | -0.967 | -0.8438 |

Most sensitive

Threshold Days of Special Vegetation indices



Maximum Days: 33(SEex1), 21(SEex2), 33(SEex3)

Correlation Coefficients and sensitivities of some special vegetation indices

| Vegetation Indices | Correlation coefficient | | | Difference (%) # | | | |
|---|-------------------------|----------|----------|-------------------|--------|--------|---------|
| | SEex1 | SEex2 | SEex3 | SEex1 | SEex2 | SEex3 | Average |
| $EVI = \frac{(1+L)(NIR-red)}{(NIR+C1*red-C2*blue+L)}$ | -0.4520 | -0.7591* | -0.4075 | -8.28 | -34.15 | -22.51 | -21.65 |
| $ARVI = \frac{(NIR - (2red - blue))(NIR + (2red - blue))}{(2red - blue)}$ | 0.1541 | -0.7152* | -0.8749* | -9.09 | -40.35 | -27.87 | -25.77 |
| $MSAVI2 = \frac{1}{2} * \frac{[(2*(NIR+1)) - ((2*NIR+1)^2 - 8(NIR-red))^{\frac{1}{2}}]}{1}$ | -0.7377* | -0.9140* | -0.6319* | -5.50 | -18.39 | -9.09 | -10.99 |
| $GEMI = \frac{(1-0.25*red - 0.125*red^2)}{(1-red)}$ $ \frac{2(NIR^2 - red^2) + 1.5NIR - 0.5red}{(NIR+red+0.5)} $ | -0.6088* | -0.9042* | -0.1881 | -4.71 | -18.42 | -9.56 | -10.90 |
| $DVI = NIR - Red$ | -0.5799 | -0.9140* | -0.1757 | -9.14 | -33.14 | -19.53 | -20.61 |

Sensitive bands and vegetation indices

| Band(nm) | Ranking | Vegetation indices | Ranking | Vegetation indices | Ranking |
|----------|---------|--------------------|---------|--------------------|---------|
| 694 | 1 | VI2_800_694 | 1 | RVI_900_580 | 14 |
| 630 | 2 | VII_830_560 | 2 | RVI_900_670 | 15 |
| 620 | 3 | RVI_800_694 | 3 | RVI_950_620 | 16 |
| 660 | 4 | RVI_800_630 | 4 | RVI_900_680 | 17 |
| 580 | 5 | RVI_900_694 | 5 | RVI_950_580 | 18 |
| 670 | 6 | RVI_800_620 | 6 | RVI_950_670 | 19 |
| 680 | 7 | RVI_900_630 | 7 | RVI_830_560 | 20 |
| 560 | 8 | RVI_950_694 | 8 | RVI_950_680 | 21 |
| | | RVI_800_670 | 9 | RVI_830_485 | 22 |
| | | RVI_900_620 | 10 | RVI_800_450 | 23 |
| | | RVI_830_660 | 11 | RVI_900_450 | 24 |
| | | RVI_950_630 | 12 | NDVI_830_560 | 25 |
| | | RVI_800_680 | 13 | RVI_950_450 | 26 |
| | | | | MSAVI2 | 27 |

Most sensitive

Differentiating greenbug infestation and water stress

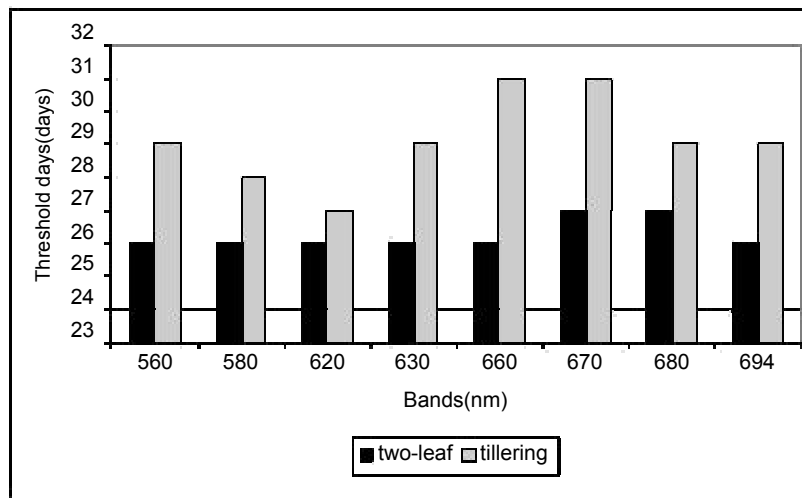
| | Threshold Days | | |
|-------------|-----------------|-----------------|-----------------|
| Band (nm) | DIex1(Nov 2002) | DIex2(Mar 2003) | DIex3(Nov 2003) |
| 560 | no | 27 | 28 |
| 580 | no | 24 | 31 |
| 620 | 34 | 27 | 32 |
| 630 | 34 | 27 | 32 |
| 660 | 32 | 27 | 34 |
| 670 | 32 | 27 | 36 |
| 680 | 34 | 27 | 35 |
| 694 | 34 | 27 | 34 |
| Maximum Day | 18 | 21 | 33 |

Note: there are no Threshold Days

Threshold Days of Selected VI used to differentiate water stress from infestation

| Vegetation indices | DIex1(Nov 2002) | DIex2(Mar 2003) | DIex3(Nov 2003) |
|--------------------|-----------------|-----------------|-----------------|
| NDVI_830_560 | 17 | 27 | 31 |
| RVI_800_450 | no | 25 | 31 |
| RVI_800_694 | 18 | 22 | 28 |
| RVI_830_485 | 30 | 25 | 33 |
| RVI_830_660 | 18 | 22 | 29 |
| RVI_900_620 | 17 | 27 | 28 |
| RVI_900_630 | 18 | 27 | 28 |
| RVI_900_680 | 17 | 24 | 28 |
| RVI_900_694 | 18 | 21 | 28 |
| RVI_950_670 | 21 | 27 | 28 |
| RVI_950_680 | 20 | 24 | 28 |
| RVI_950_694 | 18 | 21 | 28 |
| VI1_830_560 | 17 | 26 | 31 |
| VI2_800_694 | 18 | 22 | 28 |
| MSAVI2 | 21 | 28 | no |
| Maximum Day | 18 | 21 | 33 |

Impact of stage on detection for bands



Comparing aphid infestations

| Band(nm) | GB-Control | RWA-Control | GB-RWA |
|-------------|------------|-------------|--------|
| 560 | 14 | 13 | no |
| 580 | 14 | 13 | no |
| 620 | 15 | 13 | no |
| 630 | 15 | 13 | no |
| 660 | 17 | 9 | no |
| 670 | 17 | 13 | no |
| 680 | 17 | 13 | no |
| 694 | 15 | 13 | no |
| Maximum Day | 18 | 18 | |

note: there are no Threshold Days

GB-Control: comparison between plants infested by GB and control plants;

RWA-Control: comparison between plants infested by RWA and control plants; GB-RWA: comparison between plants infested by GB and plants infested by RWA;

Threshold Days of Select VI Used to compare two kinds of infestations

| Vegetation indices | GB-Control | RWA-Control | GB-RWA |
|--------------------|------------|-------------|--------|
| RVI_800_450 | 18 | 9 | 9 |
| RVI_800_620 | 15 | 9 | no |
| RVI_800_694 | 16 | 9 | 20 |
| RVI_900_670 | 16 | 11 | 20 |
| RVI_900_680 | 16 | 9 | 20 |
| RVI_900_694 | 15 | 11 | 19 |
| RVI_950_450 | 18 | 9 | 9 |
| RVI_950_580 | 14 | 9 | 19 |
| RVI_950_620 | 14 | 9 | 20 |
| RVI_950_630 | 15 | 9 | 19 |
| RVI_950_694 | 15 | 9 | 19 |
| VI1 | 14 | 9 | no |
| VI2 | 16 | 9 | 20 |
| MSAVI2 | 16 | 9 | no |
| NPCI | 16 | no | 16 |
| YI | 17 | no | 14 |

Sensitive bands

| Band (nm) | Differentiate W and I | Stage impact | Differentiate G & R | Sensitive bands(?) |
|-----------|-----------------------|--------------|---------------------|--------------------|
| 694 | v | # | x | * |
| 630 | v | # | x | * |
| 620 | v | # | x | * |
| 660 | v | # | x | * |
| 580 | x | | x | |
| 670 | v | | x | |
| 680 | v | # | x | * |
| 560 | x | | x | |

W: water stress, I: Infestation, G: greenbug infestation, R: infestation by RWA
v: can be used, x: cannot be used, #: can be used at both stages, *:sensitive band

Conclusions

- Sensitive bands:
(Visible Red) 620, 630, 660(broad), 680, 694 nm
- Sensitive vegetation indices:
VI2_800_694, RVI_800_694, RVI_950_694,
RVI_950_620, RVI_900_680, RVI_950_680
- Landsat TM bands and derived vegetation indices such as VI1_830_560 could be used to detect aphid infestation.
- It is possible to detect greenbug infestation using sensitive bands or vegetation indices determined in this study.

Future research needs

- Hyper-spectral study using ASD spectrometer (350-2500 nm) at 2 nm resolution
- Differentiate greenbug infestation with nutrient deficiency and plant diseases
- Field studies to test sensitive bands and vegetation indices
- Investigate the unique spatial patterns caused by greenbug infestation
- Developed detection method by remote sensing to an effective decision tool for farmers

iii. Aircraft Based Russian Wheat Aphid Remote Sensing

Written by Thomas Dvorak, University of Iowa, Iowa City, IA Other Participants, Mustafa Mirik, Gerald J. Michels Jr., Norman C. Elliott, Sabina Kassymzhanova-Mirik, Roxanne Bowling, Vanessa Carney, Lana Castleberry, Johnny Bible, Bob Villarreal, Joy Newton, Denial Jimenez, Vasile Catana, Timothy D. Johnson

Introduction. The Russian wheat aphid is a serious threat to small grains including wheat and barley. Early detection of the pest is essential for management strategies including pesticide application. Due to environmental concerns and the small profit margin associated with small grain production, the decision to use an insecticide during a pest outbreak is crucial to farmers (Royer, Giles and Elliott 1998). With timely and precise detection of Russian wheat aphid presence, pest control measures could be carried out in a way that reduces economic losses and environmental impacts (Yang et al., in press). The purpose of this project is to examine multi-spectral remote sensing for its utility in detecting Russian wheat aphid infestations in wheat fields.

Background. The Russian wheat aphid is not native to the United States. The first US specimen was found in March of 1986 in the Texas panhandle. The Russian wheat aphid is small ($< 1/10$ inch) and greenish to grayish green. The shape of the insect is distinctive. It is more elongate than other aphids and the antennae and cornicles are short. Population explosions of Russian wheat aphids cause a speedy progression of crop damage in infested fields. Under heavy infestations, severe yield reductions of up to 100% are possible, and grain test weights can be reduced to only 20 percent of normal (Hein et al 1998).

Objectives.

- Use remote sensing to detect the presence of Russian Wheat Aphids in field plots.
- Examine the relationship of mean Normalized Difference Vegetation Index (NDVI) and density of aphids in each test plot.
- Determine if remote sensing is capable of differentiating stresses caused by drought and the Russian Wheat Aphid.

Study Area. The study area was located in southeastern Colorado in Baca and Prowers Counties (see figure on left below). One wheat field was examined in each county. It is important to note that these wheat fields were already under some drought stress in addition to the Russian wheat aphid presence (see figure below to right). Each field had 24 3x3 meter plots. White towels were laid down in the field to locate the plots in the image. They appear as small white dots in the image. Twelve plots were located in highly infested parts of each field, and 12 plots were located in less infested parts. Aphid density was determined for each plot. Immediately after sampling the plots for Russian wheat aphids, remote sensing imagery was obtained using a multi-spectral imaging system called the SSTCRIS. With these data, we could compare aphid density for each plot with reflectance intensity in remote sensing imagery for the plot.



Study Area (Wheat Fields)

- Grower #51
- Grower #53



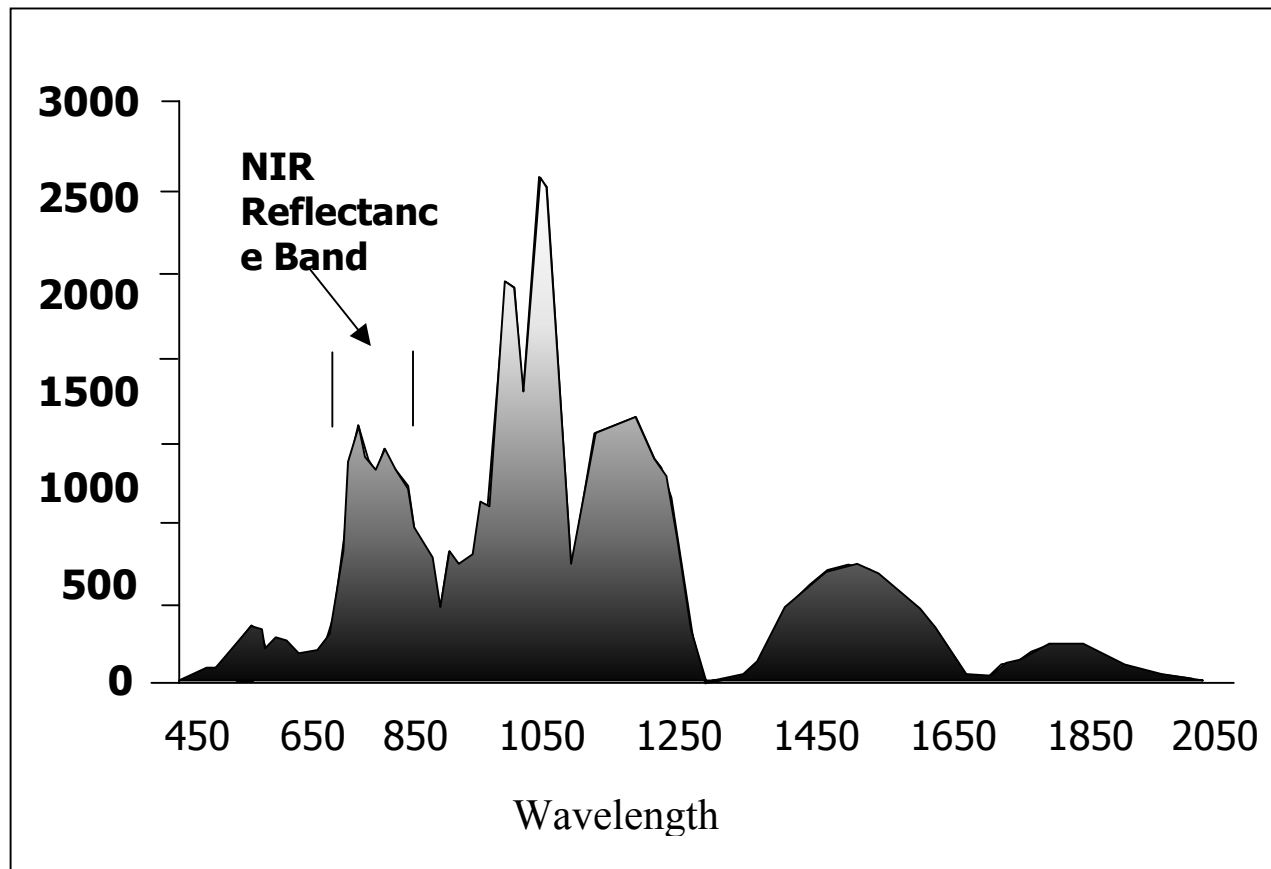
False color composite of study area in the Gower #53 field demarcated by four tarps.

Plant Stress and NDVI. When Russian wheat aphids feed on a plant and the plant becomes damaged, the plant is stressed. Plant stress is the deviation from the optimal conditions for growth, and could cause harmful effects when the threshold of the plants' ability to compensate is reached (Larcher 1995). Plant stress can occur due to water deficiency, nitrogen deficiency, insect infestation, disease, and other causes.

The Normalized Difference Vegetation Index is a commonly used and effective way to detect plant stress. The near-infrared band and red band of remotely sensed images are used to calculate NDVI.

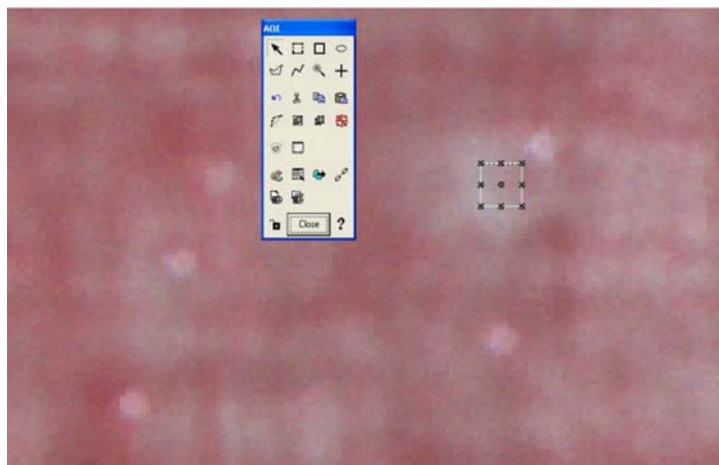
$$NDVI = (NIR - red) / (NIR + red)$$

Plants under stress show a decrease in reflectance in the NIR spectrum and reduced absorption of light in the photosynthetic spectrum (Shibayama et al. 1993). Due to these properties, reflectance can be used to assess stress levels in plants (Fernandez et al. 1994) (see figure below).



Methods

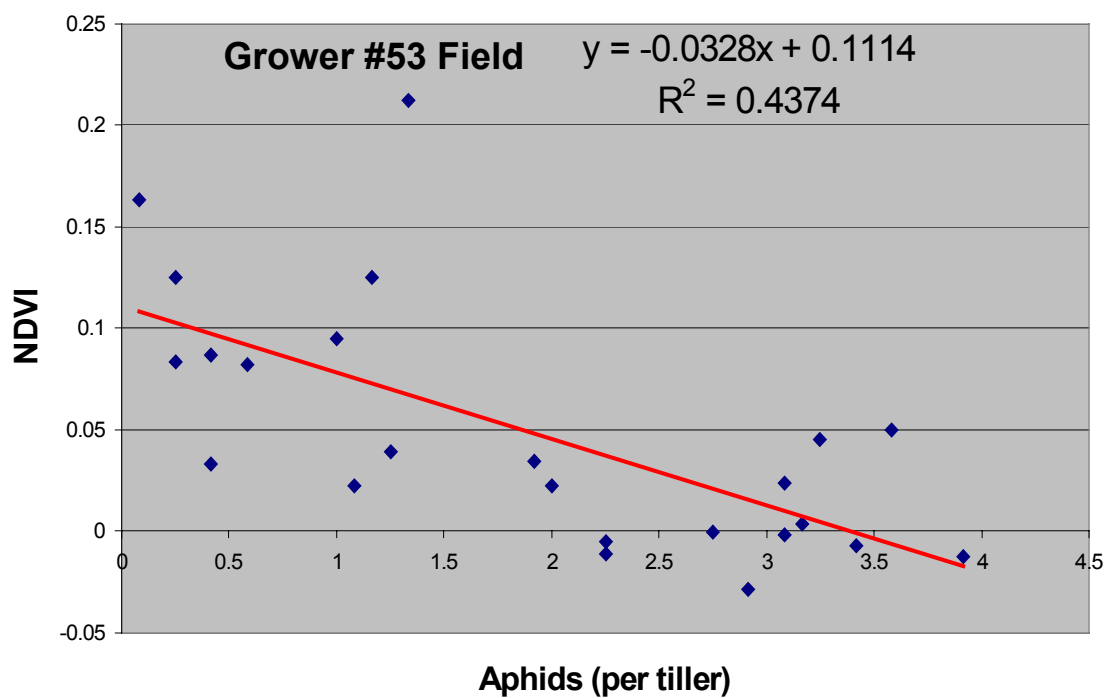
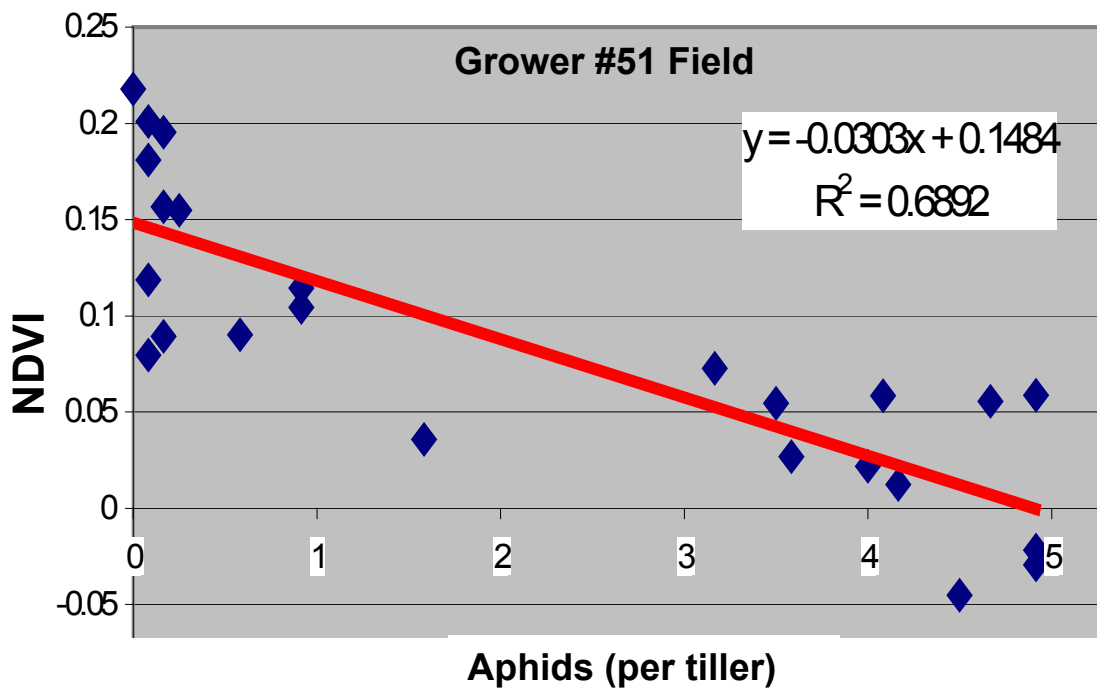
- Re-project images to the UTM Nad 83 zone 13 north coordinate system using ERDAS Imagine 8.6 software. Georeference the aerial remotely sensed images to the point layer of tarp and towel locations using ERDAS Imagine 8.6.
- Use towel point layer to identify correct locations of plot corners.
- In ERDAS, create AOI's (areas of interest) of 2x2 meter plot area one meter SW of the towels used to mark the NE plot corner. This was done for all 48 plot locations in the Grower #51 and Grower #53 fields (see figure below).
- Create subsets for each plot from AOI areas in ERDAS.
- Convert all pixels within each subset to a spreadsheet format from which to calculate mean NDVI for each plot.



Results and Conclusions. We have shown that multi-spectral remotely sensed data was sensitive to variation in the density of Russian wheat aphids in production wheat fields. Both fields studied showed lower NDVI values for highly infested plots than for less infested plots (see figures on next page). Despite the fact that the fields were drought stressed, Russian wheat aphid presence could still be identified using the NDVI values for each plot. The Grower #51 field showed a high coefficient of determination (.69) between Russian wheat aphid density and NDVI. Lower NDVIs were found in plots with higher Russian wheat aphid densities indicating that the additional stress caused by Russian wheat aphids in the drought stressed field was evident in the imagery. The Grower #53 field was not as heavily infested with Russian wheat aphids and that may explain the lower coefficient of determination (.44). Results of this study were encouraging, and indicate that further research is warranted to determine whether multi-spectral remote sensing can be used for detecting Russian wheat aphid infested fields in operational pest management programs for the pest.

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b. Natural Enemy Dynamics in Diversified Cropping Systems

i. Field evaluation of natural enemy dynamics in diversified and continuous wheat and sorghum cropping systems.

Written by Mpho Phoofolo

Other Participants, Amber Kelly, Kris Giles, Norm Elliott, Dean Kindler, and Tom Royer

INTRODUCTION. The strategy of crop production through intercropping is viewed by many as a cornerstone for sustainable agriculture (Vandermeer 1989; Altieri 1994; Sullivan 1998). One of the benefits of intercropping is low insect pest pressure in production systems. Low insect pest pressure is an outcome attributed to factors explained by two hypotheses: the “natural enemy hypothesis” and the “resource concentration hypothesis” (Root 1973; Andow 1991).

The natural enemy hypothesis is based on the efficiency of predators and parasitoids in controlling herbivore populations in natural ecosystems. Natural ecosystems are typically characterized by spatial and temporal resource stability whereas resources in agroecosystems, dominated by monoculture, are ephemeral (Wiedenmann & Smith 1997). The ephemeral nature of resources is assumed to curtail the efficiency of natural enemies in monoculture production systems. Therefore, intercropping strategies, that ensure the spatial and temporal availability of resources to natural enemies, are considered to have pivotal components of sustainable insect pest management programs.

The objective of this study is to determine the potential of relay intercropping in enhancing natural enemy activities within the cereal production system. The goal is to determine how the mix of crops influences populations and communities of aphids and their associated natural enemies at the field scale. Preliminary results from this on-going study are reported.

MATERIALS AND METHODS. This study is being conducted at two sites, Perkins, OK and Chickasha, OK, and each site divided into nine plots. Three of the nine plots are diversified crops (40 x 160 ft strips of alfalfa, wheat, sorghum, and cotton), three are wheat monocultures (160 x 160 ft), and the remaining three are sorghum monocultures (160 x 160 ft). Each of these plots was randomly located within a 10.2 acre field. The plots are separated by 40 ft alleys that are kept fallow at all times. September 2003, plots were laid out at both study sites, during which alfalfa and wheat were planted in randomly selected areas [Note: sorghum and cotton will be planted in late spring and summer 2004, respectively and thus are not included in the results].

Predator Sampling: Random placement of a 0.5 m² quadrat (= a metal ring [80 cm diam. by 20 cm high]) in 4 random locations per plot followed by vacuuming each quadrat for 1.5 minutes with a suction sampler (Poulan PRO®). [Note that for monoculture plots only designated plot areas equivalent in size to diverse strips are sampled.] Density of predators is determined from counts per suction sample.

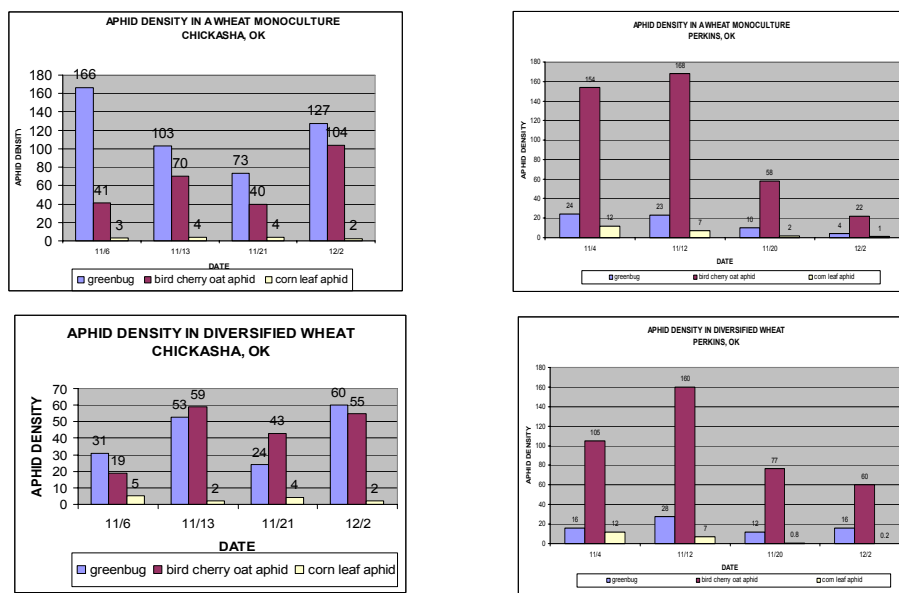
Densities reported are from 3 sampling dates for Chickasha (11/13/03, 11/21/03, and 12/02/03) and two sampling dates for Perkins (11/21/03 and 12/02/03). Yellow Pherocon® AM sticky traps mounted (stapled) on wooden stakes (2 ft above ground) so that the trap has two surfaces, east-facing and west-facing. Reported densities are from 2 sampling dates, 11/21/03 and 12/02/03, for each site.

Aphid Sampling: A random selection of 100 tillers per wheat plot and a total of 50 stems per alfalfa plot was collected to determine aphid species density. Each tiller/stem was cut at

ground level, placed in a labeled bag until sorting and identification. Collected aphids were identified to species and enumerated. Mummies were counted and aphids dissected to determine percent parasitism, however, parasitism data are not included in the results.

Analysis: Predator and aphid densities were statistically analyzed using a one-way analysis of variance, with monoculture wheat, diverse wheat, and alfalfa as factors. The analyses were done separately for each sampling date for each site.

RESULTS AND DISCUSSION. Aphid population densities (of individual species and the total number of co-occurring species) did not show any clear temporal pattern in Chickasha wheat plots (see figure below). This was unlike the situation in Perkins where densities of bird-cherry oat aphids (BCOA) were higher during early November. Furthermore, BCOA was the most abundant aphid in Perkins whereas this was not the case in Chickasha, where greenbugs were as abundant as BCOA. In terms of the comparison between aphid densities in wheat monoculture and diverse wheat, differences were only apparent in Chickasha where the wheat monoculture plots harbored more aphids in three out of four sampling dates. Although we did not statistically compare aphid densities between alfalfa and wheat it appears as though both wheat plots tended to have more aphids than alfalfa. The spotted alfalfa aphid was, in most cases, the only species found in alfalfa.



Population densities of many predators in Chickasha were relatively low across crop types during all three sampling dates (Table 1). For example, lady beetles like *Coleomegilla maculata* and *Coccinella septempunctata*, that are normally common in crops, were totally absent. Lady beetle larvae were actually found more often than the adults in suction samples. The most abundant predators in Chickasha were anthocorids (*Orius* spp.), anthicids, and spiders. Anthocorids were found almost exclusively in alfalfa. Anthicids and spiders were also significantly more abundant in alfalfa than in both diverse and monoculture wheat plots.

Table 1. Numbers of predators caught on Chickasha sticky traps

| | PREDATORS | | | | | | |
|----------------------|---------------------------|--------------------------------|-------------------------------|-----------------|--------------------|----------------|-----------|
| CROP | Convergent l. beetle | Seven- spotted l. beetle | Pink- colored l. beetle | Rove Beetles | Green lacewings | Hover flies | Spiders |
| | DATE | | | | | | |
| | November 25 / December 02 | | | | | | |
| Monoculture Wheat | 0.1 / 0.1 | 0 / 0.03 | 0.1 / 0.1 | 0 / 0.6 | 0.9 / 1.2 | 1.3 / 2.6 | 0.2 / 1.8 |
| Diverse Wheat | 0.1 / 0.2 | 0.03 / 0.03 | 0.1 / 0.2 | 0 / 0.6 | 0.6 / 0.9 | 1.0 / 2.4 | 0.2 / 2.4 |
| Alfalfa | 0.1 / 0.1 | 0.03 / 0.08 | 0.2 / 0.2 | 0 / 0.9 | 0.9 / 0.9 | 1.6 / 3.1 | 0.1 / 2.2 |

In Perkins plots, population densities of most predators were also relatively low across the crop types and dates, with many averaging <1 per 0.5 m² quadrat. Exceptions to this trend were found in anthocorids, staphylinids, anthicids, and spiders all of which occurred in significantly higher densities in alfalfa. Differences between diverse and monoculture wheat were significant only in the November densities of Anthicids. The occurrence of more predators in alfalfa than in the two wheat systems is an interesting outcome, especially given that the aphid density situation is quite the opposite.

Table 2. Numbers of predators caught on Perkins sticky traps.

| | PREDATORS | | | | | | |
|----------------------|---------------------------|--------------------------------|-------------------------------|-----------------|-------------------|----------------|------------|
| CROP | Convergent l. beetle | Seven- spotted l. beetle | Pink- colored l. beetle | Rove beetles | Green lacewing | Hover flies | Spiders |
| | DATE | | | | | | |
| | November 25 / December 02 | | | | | | |
| Monoculture Wheat | 0.03 / 0.06 | 0.03 / 0.03 | 0 / 0.03 | 0 / 0.7 | 0.9 / 0.9 | 6.6 / 17.8a | 0.1 / 1.0 |
| Diverse Wheat | 0.03 / 0.06 | 0.03 / 0.03 | 0 / 0.03 | 0 / 0.4 | 0.7 / 0.7 | 7.9 / 19.5ab | 0.06 / 0.6 |
| Alfalfa | 0 / 0.03 | 0 / 0 | 0 / 0 | 0 / 0.3 | 0.8 / 0.8 | 8.8 / 23.3b | 0.03 / 1.0 |

Hoverflies were the only group of predators that appeared in relatively high numbers on the sticky traps. This was particularly the case in Perkins, where >20 flies per trap were found. It is important to note that there were very low densities of hoverfly larvae in the suction samples (Table 2). This implies either low reproductive activity during the sampling period or that the adults were not resident in the plots but only got attracted to the yellow color of traps.

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ii. An evaluation of how Coccinellids deal with the starvation that likely occurs in the field during transitions among crops in a diversified cropping system.

Written by Mpho Phoofofo
Other Participants, Kris Giles and Norm Elliott

How do coccinellids deal with nutritional stress?

MW Phoofolo¹, NC Elliott² & KL Giles¹

¹Dept. of Entomology & Plant Pathology
Oklahoma State University

²USDA-ARS, Plant Science Research Lab.
Stillwater, Oklahoma

- Nutritional stress is a common phenomenon among insect predators, including coccinellids

Evidenced by

- field observations
 - Lack of co-occurrence of coccinellid larvae and prey spp. on plants
 - Intra-guild predation, cannibalism, and omnivory are feeding behaviors that indicate nutritional stress
- Large variation on body sizes of field collected adult coccinellids



Objectives

- Determine how *Hippodamia convergens*, *Colleomegilla maculata*, and *Harmonia axyridys* respond, in terms of their life history traits, to nutritional stress (starvation)
- Determine existence of threshold weight for metamorphosis in the three species



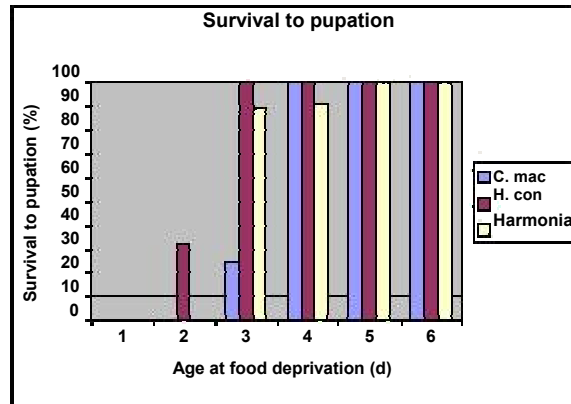
Fitness traits evaluated (at 22° C, L16:D8)

- Survival to pupation
- Age at metamorphosis
- Body size at metamorphosis
- Length of pupal stadium
- Adult size

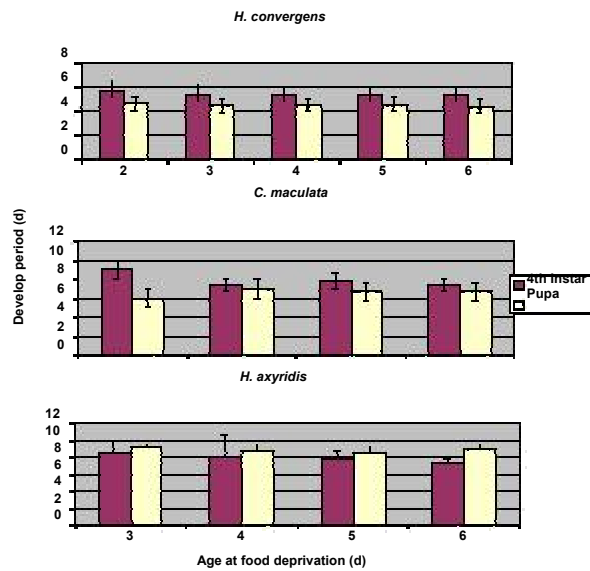
Stage subjected to different levels of nutritional stress = 4th instar

Study design

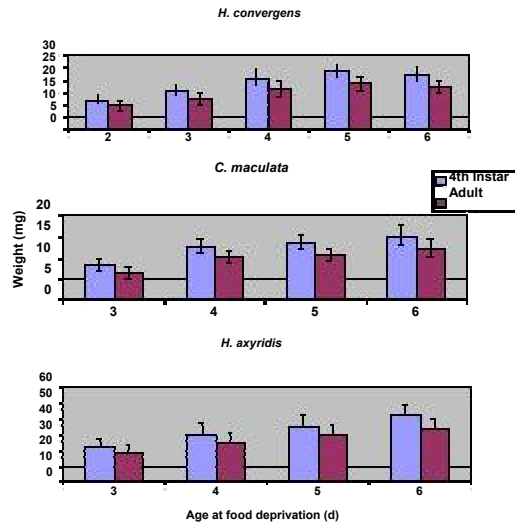
| Age at food deprivation (d) | Feeding regimen of 4 th instars |
|-----------------------------|--|
| 1 | Starved throughout |
| 2 | Fed for 1 day only |
| 3 | Fed for 2 days |
| 4 | Fed for 3 days |
| 5 | Fed for 4 days |
| 6 | Fed for 5 days |



Age at metamorphosis



Size at metamorphosis



Coccinellids express:

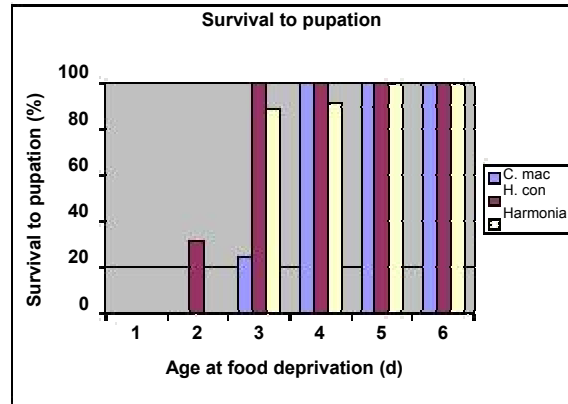
1. Developmental homeostasis or canalization

- In age at metamorphosis = development time
- i.e., the case in which the same phenotype results regardless of environmental variation.

2. Phenotypic plasticity

- In body size (larval size at metamorphosis and adult size)
- i.e., the case in which a change in the phenotype that depends on the environment.

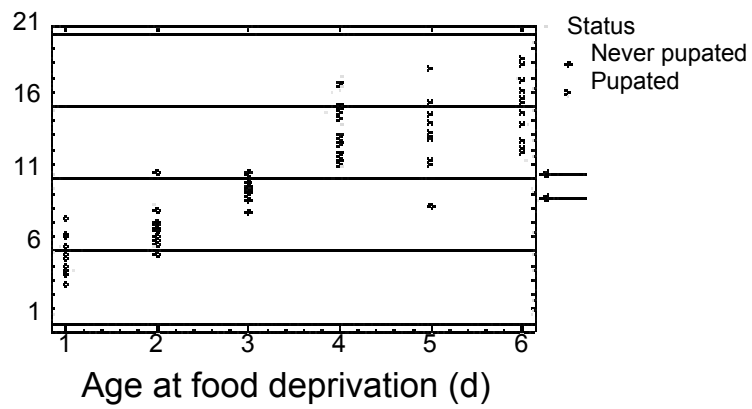
Is there a threshold weight for metamorphosis?



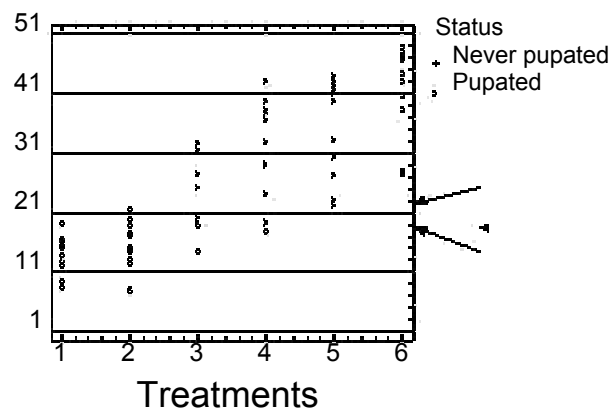
H. convergens max. larval weight



C. maculata max. larval weight



Harmonia max. larval weight



Summary

- Coccinellids respond to nutritional stress by
 1. Maintaining the same development time
 2. Changing body size at metamorphosis and maturation
- Coccinellids display a threshold body size, below which further development is not possible (unless they are released from nutritional stress).